THE UNIVERSITY OF CHICAGO

The Estimation of the United States Conventional Milk Demand Elasticity

By

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1. Introduction

The dairy industry has always been a protected market sector in the United States, which gains substantial government subsidies every year. For example, in 2016, this sector received 43 billion dollars of funds from the U.S. government and 36.3 billion in 2017 (Luiz, 2022). To estimate the amount of the subsidy for the dairy industry, it is necessary for the U.S. government to estimate the demand elasticity of the dairy market.

In addition, there exists another reason for academic scholars and private sectors to update the research on dairy market demand elasticity: although a lot of literature on demand elasticity has been published over the last century, the updating is needed. Maynard and Liu (1999) mentioned that there are a lot of factors that influence people's consumption of dairy products that have changed over the years (such as breakfast cereal consumption dropped, demographic variations, and related policy changes). Moreover, the U.S. government was once the biggest consumer of domestic dairy production, but this situation has changed recently (Merlo, 2015).
Last but not least, there is a dramatic increase in demand from the international dairy market during recent decades mainly due to the significant economic growth and profound welfare improvement in Asia and Latin American countries (MacDonald et al., 2016), which could potentially influence the domestic demand elasticity of dairy products.

The rising trend of milk alternatives (such as soymilk, almond milk, rice milk, etc.) may also predict the change in domestic dairy demand: In recent years, the technology upgrading in nutrient formula leads milk alternatives increasingly gained popularity in the U.S. domestic market, as the milk alternatives producers are adding a variety of beneficial nutrient like vitamin

E and D in these plant-based milks, and this trend comes along with the popular understanding of certain natural ingredient from the conventional dairy, which could cause hormone irregularity, as one of the major drawbacks of the conventional milk (Copeland & Dharmasena, 2016); additionally, vegetarian diet choice has gained massive popularity (due to the influence of the food pop culture and the environmental friendly education). Consequently, the demand for alternative dairy choices grows exponentially, for instance, its global market is expected to reach $53.97 billion in 2028, from the already $22.25 billion in 2021 ("Dairy Alternatives Market Size"). Namely, the "alternative dairy choices" is a substitute for conventional dairy for most consumers: as the demand for these dairy alternatives increases, the demand for conventional dairy is expected to drop, which fact has been proved by Copeland and Dharmasena's empirical study.

As a result, it is meaningful to study the dairy market's demand elasticity by using the data from recent years. In this paper, I used the instrumental variable (IV) approach to study the recent U.S. domestic conventional dairy market demand elasticity, using the agricultural datasets from 2017 to 2021, with the goal of providing the recent dairy demand elasticity as the major outcome of this study.

2. Background and Literature Review

To study market elasticity, it is very common to use the instrumental variable (IV) approach, because of the inherent existence of omitted variable bias (OVB) issue in estimating the elasticity of market demand. Gaining insights from the BLP (a regression technique shared by Berry, Levinsohn, and Pakes in 1995) method in estimating the demand elasticity, my paper used the IV approach to study the US domestic dairy market's demand elasticity.

There is already an abundance of case studies and academic papers regarding the estimation of the US dairy market demand elasticity, for example, an empirical study from Boehm and Babb (1975) found that the domestic own-price elasticity of whole milk is -1.7, and elasticity of 2% milk and canned milk is -1.33; another academic papers studying the demand elasticity has suggested that demographic variables have a very significant contribution in estimating the dairy market demand curve, and concluded that the "own-price" demand elasticity is unity or elastic for the majority of milk, while the "expenditure elasticity" for both whole milk and 1% milk is inelastic (Christopher G, 2012).

Another academic paper controlled the price, consumer income, and race ratio as independent variables, while treating the *per capita* consumption of milk as the dependent variable, and concluded that the demand for milk was elastic (Emery, 1964). The research by Emery mentioned that corn is a major source of milk cow diet, which gives me insight of using cornprice as the IV variable for my research. Moreover, based on the information source from a dairy farm at Maine, the domestic dairy farms mainly use corn as a major ingredient in the feedmix for the milk cows nowadays, aiming to maximize the nutrient quality of the dairy. However, the study from Emery was conducted in 1964, which was before the invention of BLP market demand estimation methodology, so it was not using IV to estimate the demand elasticity.

Another relatively up-to-dated study used the household purchasing data from Nielsen 2007 Homescan, and applied the "censored Almost Ideal Demand System model", which yield the conclusion that almost all dairy products (16 catagories) have elastic demand, except 4 dairy product includes ice cream, margarine, packaged cheese, and frozen yogurt; in addition, this study mentioned that demographic traits is a major explanatory variable for the model (Davis et al., 2011). Aside from the greater than 1 own-price elasticity of dairy demand, Howard and Shumway (1988) mentioned that the demand elasticity of cow and dairy farm labor (which are major inputs of the dairy production model) has also increased over time.

There exists also semi-oligopoly power from the local dairy farms. Based on the availability of datasource from USDA, only several states (14 in total, such as Texas, Ohio, Illinois, etc.) could be recognized as a specialized dairy producer states, while other states often don't have sufficiently large production quantities to be recorded by USDA . The semi-oligopoly status could be explained by the "economics of scale" requirement to reduce the production cost of the farms, and the larger farm size (like 2,000 or more head), the cost of production is lower (MacDonald et al., 2016). As a result, like other oligopoly markets, the dairy market (as well as the producers' marketing and pricing strategy) is under government regulations.

In addition, from a single state, the observed retail price could change across the season, but the overall price volatility is limited since year 2017 (see Appendix 7l, 7m, and 7o), which could be explained by the regulations and insurance plan offered to the farmers to combat the uncertainties inherently existed of agricultural production, as "Congress reorganized dairy policy in the Agricultural Act of 2014. A new program, the Dairy Margin Protection Program

(MPP-Dairy), aims to provide farmers with financial protection against adverse movements in milk and feed prices.” (MacDonald et al., 2016). Based on this information, and due to the regulation on prices, it is reasonable to expect empirical demand elasticity will lose some statistical significance, as it is not reflecting on the free market situation.

In summary, from the literatures about the dairy demand elasticity, majority of the research showed that the demand of domestic dairy is elastic, and controlling the demographic variable is necessary for most of the statistical models. From this insight, I controlled the “state” fixed effect aiming to includes all the state-level variations including the aforementioned “demographic variable.”

3. Data

I obtained my data from three main sources:

1. National Agricultural Statistics Service (NASS), Agricultural Statistics Board, United States Department of Agriculture (USDA): from this source, I obtained the monthly milk production quantity and milk per cow data from 2017 to 2021 by each of the 14 major dairy production states like Michigan, Illinois, Ohio, etc. The two key assumptions needed to utilize this dataset are: 1) the production quantity of milk would be similar to the quantity of milk sold domestically, then the data would be adapted for studying the demand elasticity. This assumption is partially reasonable as fresh dairy must be consumed within a short time period, which equalizes the production and sales quantity.

But it is worth mentioning that some of the milk produced might turn powderlized or canned for long-term storage thus for interstates or international trade, which leads the quantity of production unequal to the sales within the states. 2) The quantity I obtained here is the summation of all kinds of dairy products including organic, 2% reduced, conventional dairy, etc. However, the portion of organic dairy is limited to around 2% in the U.S., I could assume the quantity of all sorts of dairy as the quantity of conventional whole milk's quantity.

2. "Retail Milk Prices Report" from Agricultural Marketing Service, United States Department of Agriculture (USDA): from this source, I obtained the conventional whole milk prices by the 14 major dairy production states across months from 2017 to 2021.

3. Feed Grains Database, Feed Grains Custom Query, Economic Research Service, United States Department of Agriculture (USDA): from this database, I obtained the Number 2. Yellow corn monthly prices from 2017 to 2021, due to the limited number of states that are major corn producers, there are only 6 states' corn prices extracted for my analysis. My assumption is that states will buy corn at the nearlist states if they are not producing corn and if the price from the adjacent states isn't extraordinarily expensive. For example, Now York as a milk cow production state is not buying the corn at its own states, but expected to purchase the corn at Ohio, because the corn price at New York is around $16 per bushel, while the corn price at the neighboring state Ohio is on average $5 per bushel.

   Based on the dataset that was available to me, I treated every state as a unit of the observation.

4. Research Design and Hypothesis

4a. Research Design

As discussed in the introduction, I have used the instrumental variable (IV) approach to study the demand elasticity of United States domestic conventional dairy market. In order to find the right instrumental variable for the demand elasticity, the shocks from the supplyside are good candidates. As mentioned previously, dairy farms in the U.S. often prepare the feed mixture to the cows, and corn is the major ingredient in the mixture. There are fluctuations in the corn price from 2017 to 2021 (and variation in the IV is needed), and the corn price increased dramatically at the beginning of 2021 due to the well-known global supply chain crisis incurred by the 2019 pandemic. As a result, the price of corn is a convincing variable representing the supply shocks. In order to justify the candidacy of a valid instrumental variable, I provided the following reasoning: fluctuation in the corn price will influence the price of conventional dairy, as corn is the major input for the dairy production function. If the price of corn increases, the price of milk will increase too, and vice versa; however, the change in corn price will not directly affect the quantity of milk produced, as long as the milk produced per cow is stable and the daily amount of feedmix provided to the cow isn't changing for a specific dairy farm. Moreover, statistically speaking, the F-test of regressing corn price on the conventional dairy price is at 0.01 level statistically significance (see Appendix 7j). Based on the reasoning, using the corn price as the instrumental variable is justified.

In my IV regression model, I treated different states as the unit of observation. The dependent variable is the conventional milk production (unit in billion pounds) from each of the 14 states; the independent variables consist of the conventional milk retail prices, milk produced per cow (marked as "efficiency"), the state fixed effect, and the year fixed effect; the instrumental variable is the corn price faced by each state. By using the state fixed effect, it is not needed to include all other state characteristics like state-wise population or median income level; using the year fixed effect could exclude all other yearly economic shocks, including the macroeconomic shocks to the U.S. agriculture market incurred by the pandemic. The assumption for using the state fixed effect requiring the state-level characteristic is relatively stable much from 2017 to 2021. I also controlled the year fixed effect to take account of the yearly exogenous economic forces that could influence the dairy market during these 5 years.

4b. hypothesis

Hypothesis 1: Despite the elastic market demand of dairy had been concluded by the majority of previous literatures, I still believe that the market demand is inelastic. As the conventional milk is a grocery staple, which the the major source of the people's daily nutrient requirement, I expect the demand of the conventional milk is relatively inelastic.

Hypothesis 2: Influenced by the increasing popularity of alternative milk choices, it is reasonable to expect that the conventional whole milk demand elasticity will increase in recent years. I expect the conventional milk demand will be more elastic in 2019 than 2017. I didn't use the agricultural data from 2021 as a comparison with 2017, because the U.S. agricultural market in 2021 had experienced the supply chain crisis. As a result, the agricultural environment in 2019 is relatively similar to the agricultural environment in 2017, so I could see how the recent vegetarian diet trend is influencing the conventional whole milk demand elasticity.

5. Empirical result

5a. Empirical result for the hypothesis 1

Table 1

	Dependent variable:	
	ltquantity	
	(1)	(2)
lprice	-0.674	0.273**
	(1.654)	(0.122)
efficiency	0.580***	0.551***
	(0.050)	(0.020)
year_c2018	-0.017	
	(0.061)	
year_c2019	-0.018	
	(0.045)	
year_c2020	0.014	
	(0.015)	
year_c2021	0.052	
	(0.096)	
fertilizer		-0.019
		(0.012)
Constant	-1.411	-2.249***
	(1.567)	(0.086)
Observations	840	840
R2	0.994	0.997
Adjusted R2	0.994	0.997
Residual Std. Error	0.060 (df = 820)	0.043 (df = 823)
Note:	*p<0.1; **p<0.05; ***p<0.01	

As shown in Table 1, the model (1) represents the IV regression outcome while using the year fixed effect, and model (2) uses the price of fertilizer as a potential substitute for the year fixed effect. The reasoning of creating model (2) is based on the fact that: controlling the year fixed effect from model (1) is mainly aiming to control the economic shocks from the global supply chain crisis that happened since early 2021 incurred by the pandemic in early 2020, and the supply chain crisis shocked the agricultural market mainly by raising the fertilizer and pesticides cost, so controlling the fertilizer is could potentially acting as a substitute for the year fixed effect. Notice that both model (1) and (2) have controlled the state fixed effect, and the regression outcome table just omitted the 13 states fixed effect coefficient for the succinct view, which is the same for the rest of the tables.

From model (1), the coefficient corresponding to the log(price) is -0.674, which is less than one, so the recent years (from 2017 to 2021) conventional whole milk demand is inelastic, which is reasonable as previously mentioned that conventional whole milk contained essential nutrient ingredient that required by a healthy daily diet; however, as the standard deviation is 1.654, this coefficient is not statistically significant. The coefficient relating to the efficiency, the amount of milk produced per cow, is very statistically significant and it is 0.58, which could be interpreted as: on average, the increase in one thousand pound of milk produced by a cow is associated with 78.6% (0.786 = exp(0.58) -1) increase in conventional milk production for an average state, and for reference, the mean value of milk produced per cow is 1.93 thousand pounds, the maximum value is 2.34 thousand pounds, while the minimum value is 1.38 thousand pounds.

The demand elasticity coefficient from model (2) is 0.273, which is at 0.05 level of significance. Despite that the number is positive, which might be counterintuitive for a demand elasticity, 0.273 is very close to zero. As a result, the conventional whole milk demand is inelastic by controlling the fertilizer and pesticides prices in model (2). Both of the models have an R square greater than 0.99.

My interpretation for the more statistically significant result from model (2) than model (1) based on the reasoning that: if indeed the yearly macroeconomic shocks from 2017 to 2021 could be greatly explained by the supply chain crisis and the pandemic during 2020 to 2021, then controlling the yearly fixed effect from the 2017 to 2019 is unnecessary and even possible to incur the perfect collinearity problem by trying to control too much variables, as the result, the elasticity coefficient is not significant from the model (1). My evidence for the above mentioned reasoning is that: for model (1), I also tried to control the monthly fixed effect, which leads very coefficient of the independent variable has a 99.99% p-value, which depicts the potential perfect collinearity issue.

5b. Empirical result for the hypothesis 2

Table 2

	Dependent variable:	
	ltquantity2017 (1)	ltquantity2019 (2)
lprice2017	0.085	
	(0.277)	
efficiency2017	0.536***	
	(0.014)	
lprice2019		0.575
		(0.588)
efficiency2019		0.487***
		(0.066)
Constant	-2.067***	-2.439***
	(0.294)	(0.432)
Observations	168	168
R2	1.000	0.999
Adjusted R2	1.000	0.998
Residual Std. Error (df = 152)	0.011	0.031
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table 2 depicts the elasticity of conventional whole milk demand elasticity from 2017 and 2019 respectively. The difference from table 2 and the following table 3 is that table 2 didn't control the fertilizer and pesticides cost, while table 3 does, and table 3 didn't control the state fixed effect, which would be explained in the next section. Although both of the elasticity coefficient are not statistically significant (and both of them is inelastic), the conventional whole milk demand at 2017 is way less elastic than the demand elasticity at 2019, which is also consistent with the hypothesis that consumers' milk choice are influenced by the vegetarian pop culture and more popularity of milk alternatives in more recent years. Admittedly, both of the elasticity coefficients are positive, but they are very close to zero.

Table 3

	Dependent variable:	
	ltquantity2017	ltquantity2019
	(1)	(2)
lprice2017	1.132	
	(1.932)	
efficiency2017	2.016***	
	(0.735)	
fertilizer2017	0.188	
	(1.048)	
lprice2019		-0.695
		(1.892)
efficiency2019		1.756*
		(0.911)
fertilizer2019		0.037
		(0.532)
Constant	-6.235*	-3.244
	(3.247)	(3.662)
Observations	168	168
R2	0.263	0.149
Adjusted R2	0.250	0.133
Residual Std. Error (df = 164)	0.665	0.729
Note:	*p<0.1; **p<0.05; ***p<0.01	

Similar to table 2, as mentioned previously, table 3 added the fertilizer and pesticides's cost to the IV regression, while didn't control the state fixed effect. From the data source, the price of fertilizer and pesticides are the same for every states, and there is only time variations, so also controlling the state fixed effect will cause the perfect collinearity issue.

The regression outcome is that the conventional whole milk demand at 2017 is near unit elasticity while the the demand is inelastic at 2019, which result totally reversed the result from table 2. The R square in table 3 dropped significantly from 0.99 to around 0.20. Overall, this result is not as robust as the table 2, as controlling the state fixed effect is more reasonable than controlling the prices of pesticides and fertilizers; if the prices of pesticides and fertilizers could vary across states, then I would able to control both of them, thus the regression outcome would be improved from table 2.

The price of the fertilizer and pesticides (from my data source) is same across the nation majorly because of the monopoly status of fertilizer and pesticides in most countries. As a result, there is not much variation of the cost of fertilizer (only monthly variations, as the price is same for every state) and pesticides in table 3 and the unit of observation is already as low as 168, which may explain the reversed outcome than table 2.

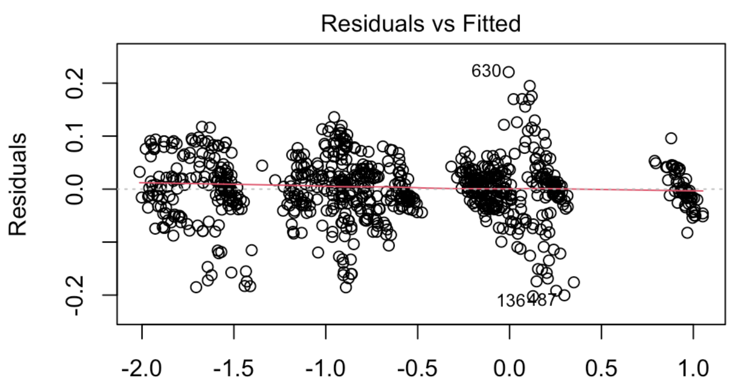
6. Conclusion and Discussion for Future Researches

Although the regression outcome from model (2) of table 1 is very statistically significant, the rest of the elasticity coefficient is lacking the statistical significance. However, from the regression outcomes, it is still evident that, by using the macro-level data of treating every state as the unit of observation, conventional whole milk demand is inelastic in recent years, which is different from the previous literatures on the demand elasticity. The inelastic outcome could be explained by the fact that previous studies are using the individual household data, which are able to depict substitution effect of dairy and milk alternatives for a single household, while the dataset used in this paper provided a state-level holistic view of the demand of dairy in large quantities. The comparison of my empirical result to previous ones could be explained as: the micro-level view of the dairy market demand is elastic, but macro-level is inelastic as some of the conventional whole milk might also goes to yogurt and cheese production, which didn't get specified from the dataset of wholemilk quantity. This interpretation is reasonable: like the demand of raw milk is usually less elastic than processed milk subcategories like cheese, yogurt, etc.

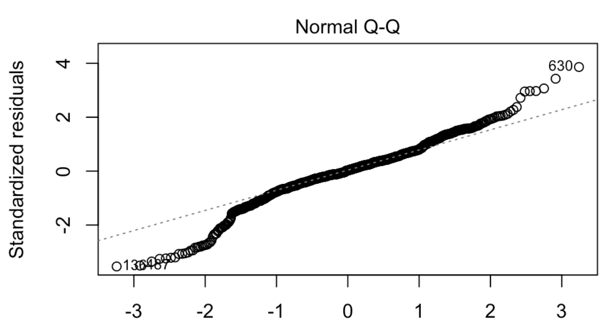
In addition, the U.S. dairy industry is regulated by the government, so the price volatility is limited, which could also explain the statistically insignificant of the elasticity coefficient. However, there exist space for future research in this topic: 1) My unit of observation is state, which inevitably reduces the significance level for the elasticity coefficient. For studying the demand elasticity, the unit of the observation is better to be sales data from different grocery stores, and the smaller unit of the observation will give a more exact coefficient in this situation. In addition, if the sales data from different grocery stores is available, the number of observations will increase dramatically, which is beneficial for the regression outcome. 2) As mentioned in the previous part, the fertilizer and pesticides price is same across the states due to the monopoly status, but the transportation cost might be different as states are in different locations, if the data of the exact transportation cost to different cow farms is available, adding transportation cost will yield a more significant result. 3) There are only 6 states that are major corn producers in my dataset, although for some states, I tooked the average price of two corn producing states that share equidistant to the dairy producing states, the variation of farm-gate corn price is still limited. 4) Although the dairy product are perishable, which means the quantity produced should equal to the quantity demanded, but my analysis didn’t take into consideration of the exported quantity of the conventional whole milk, as the U.S. is the major exporter of the dairy product worldwidely. Alternatively, If the future study could access every milk cow farm and get there specific conventional milk price, quantity produced, corn price received, transportation cost calculated at the farm-gate, I expect that the estimated elasticity would be very statistically significant.

7. Appendix

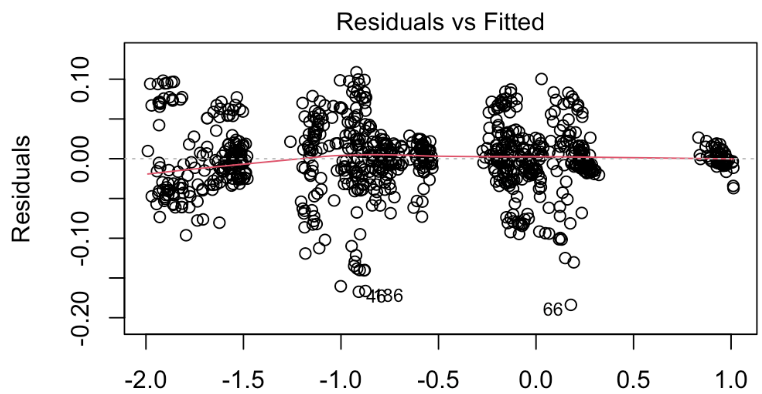
7a. Residual plot from table 1 model (1)



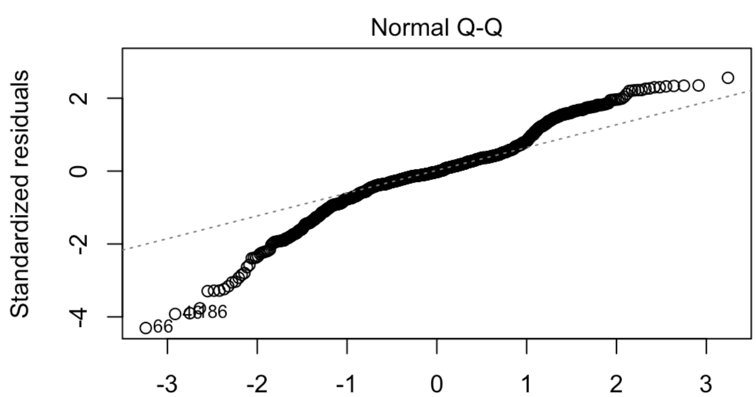
7b. QQ-plot from table 1 model (1)



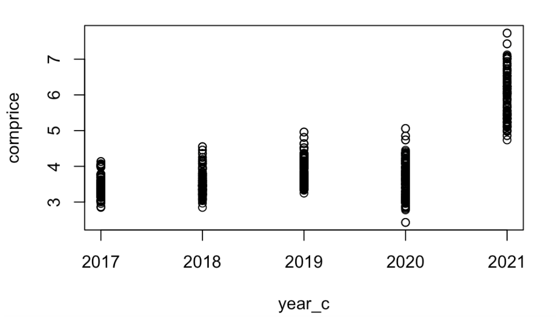
7c. Residual plot from table 1 model (2)



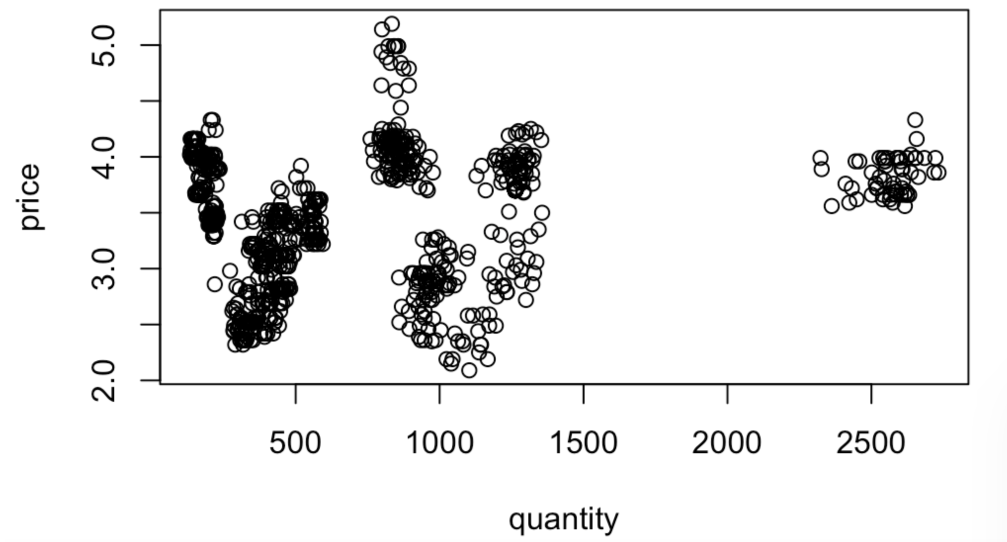
7d. Residual plot from table 1 model (2)



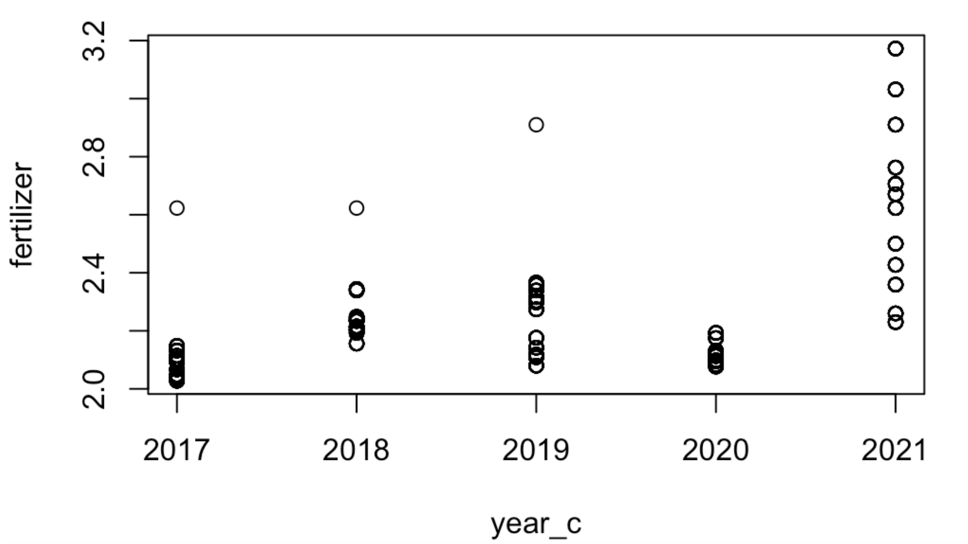
7e. Corn price by year



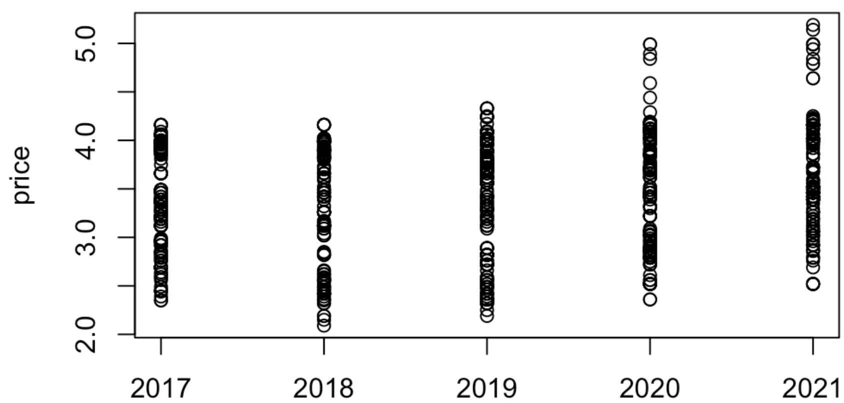
7f. Scatter plot of price vs. quantity, notice that the degree of variation is very limited, which might be due to the price regulation by several states. For example, conventional whole milk from Illinois has the same price for the whole summer and same price for the winter, so there are less monthly milk price variation for states like IL.



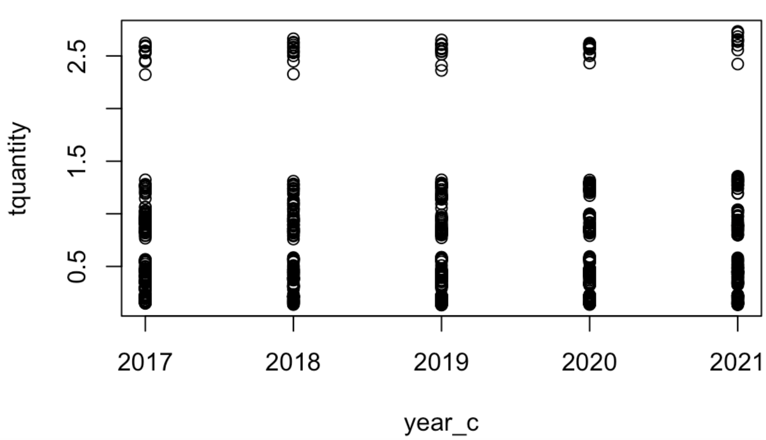
7g. Price of the fertilizer and pesticide by year, and we can see that 2021 reflects the supply chain crisis.



7h. Price of conventional whole milk by year, we could observe that the price increased from 2020, but not very dramatically, might be due to the price regulation. (the massive grocery price inflation has begin until 2022)



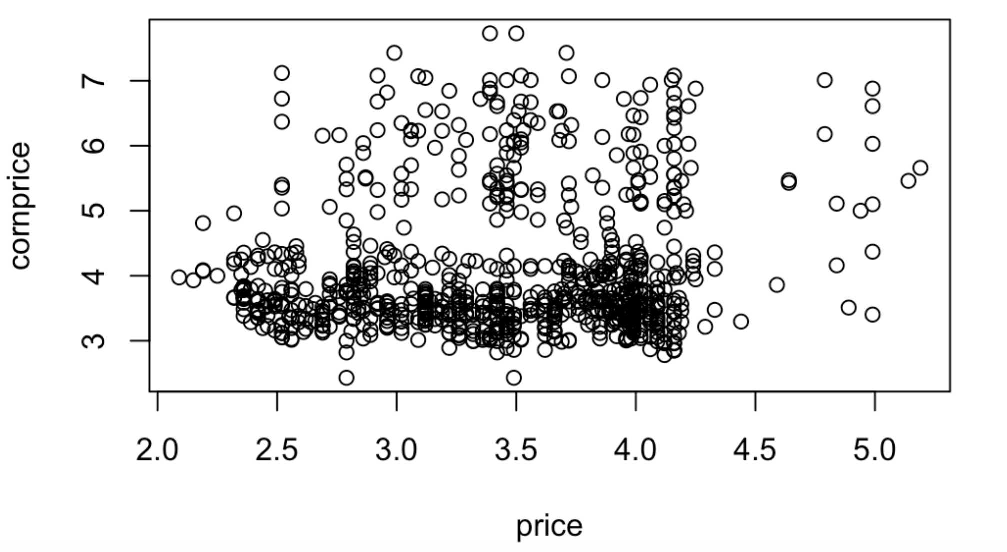
7i. Thousand million (billion) pounds of milk quantity produced in every state by year, we could observe many dots, because the units of observation also included the monthly data. From this plot, we could see the milk production didn't vary much across years, but varies significantly by states and by month.



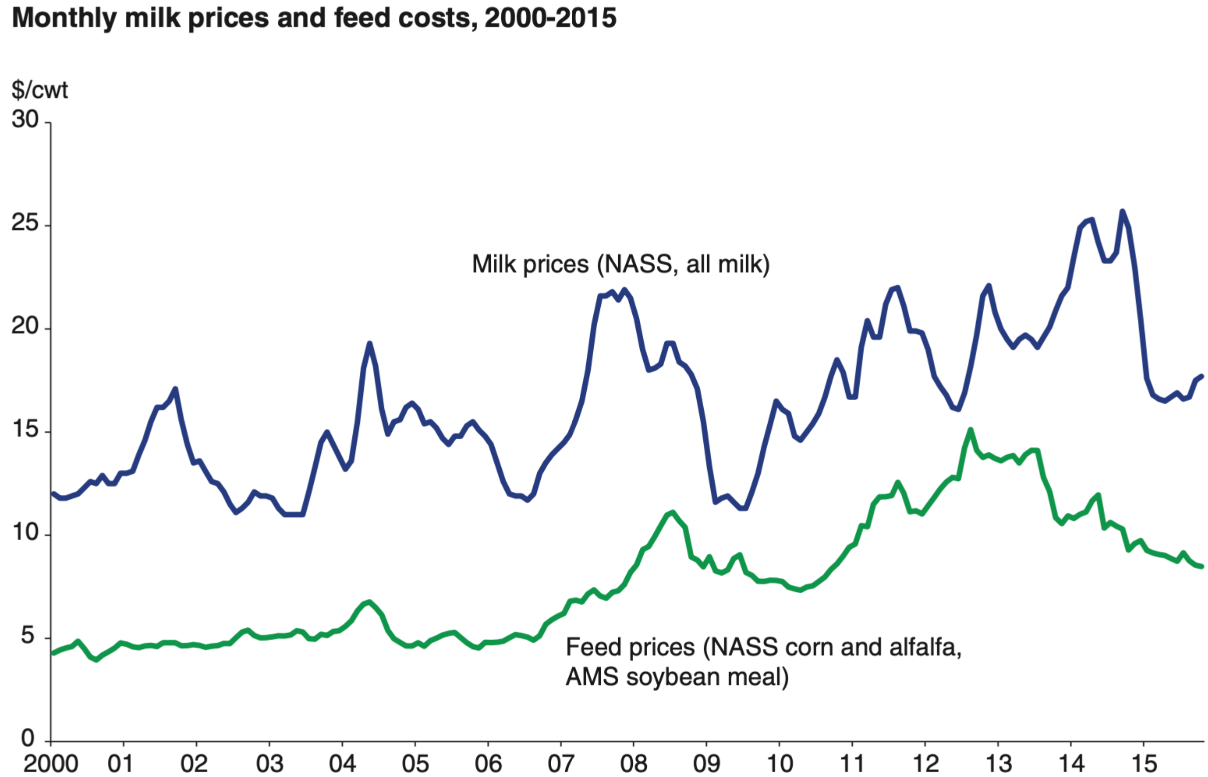
7j. The statistically significant F test shows justified the used of cornprice as the IV.

	Dependent variable: price
cornprice	0.060***
	(0.019)
Constant	3.196***
	(0.080)
Observations	840
R2	0.012
Adjusted R2	0.011
Residual Std. Error	0.584 (df = 838)
F Statistic	10.074*** (df = 1; 838)
Note:	*p<0.1; **p<0.05; ***p<0.01

7k.

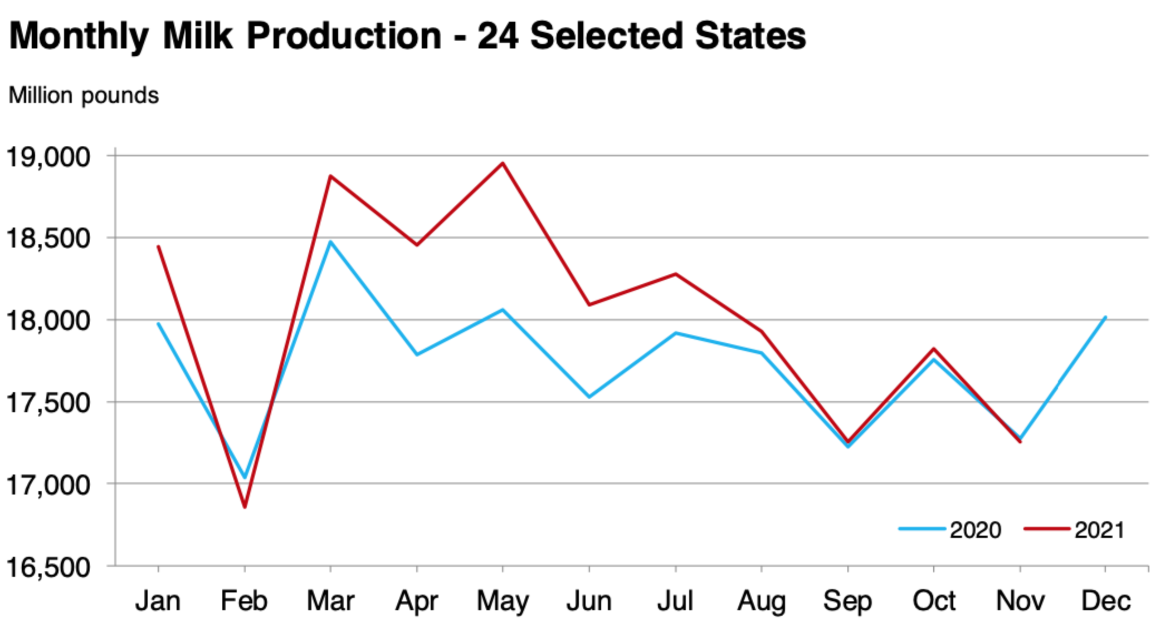


7l. 7m.



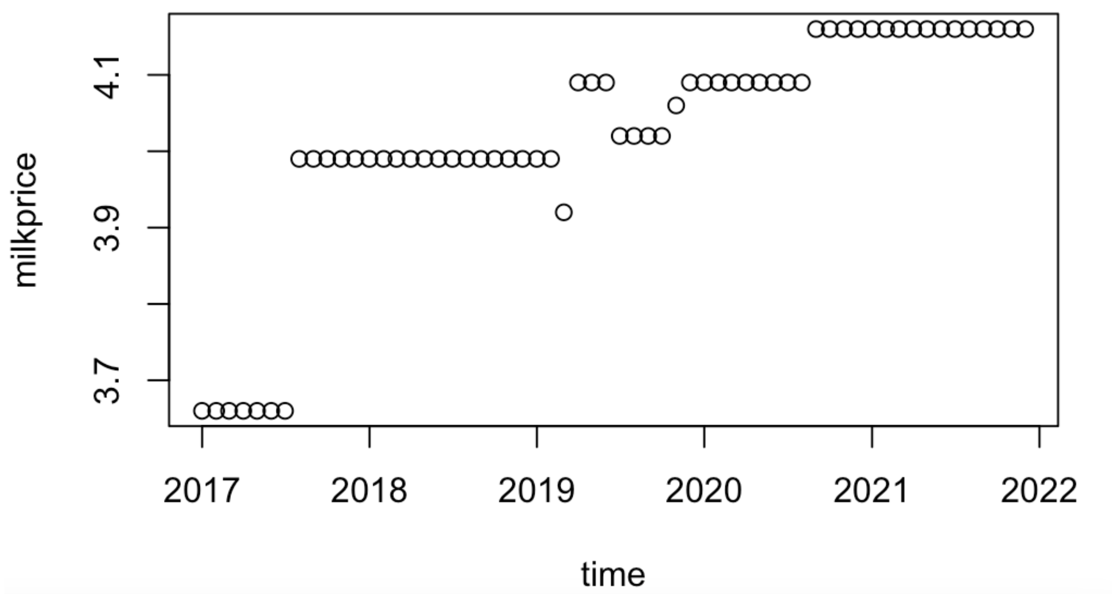
Source: USDA, National Agricultural Statistics Service (NASS) for milk, corn, and alfalfa prices; USDA, Agricultural Marketing Service (AMS) for soybean meal prices; and USDA, Farm Service Agency for feed price formula.

7n. Data source: USDA monthly dairy production report

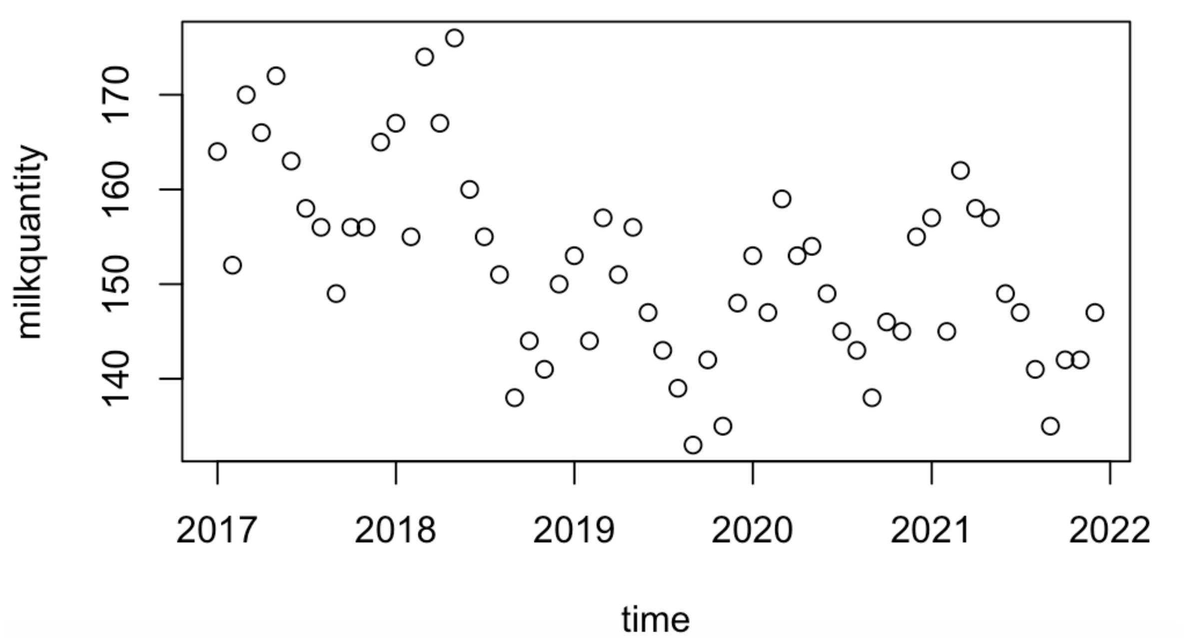


7o. Price & quantity trend at Illinois (as a typical example) from 2017 to 2021

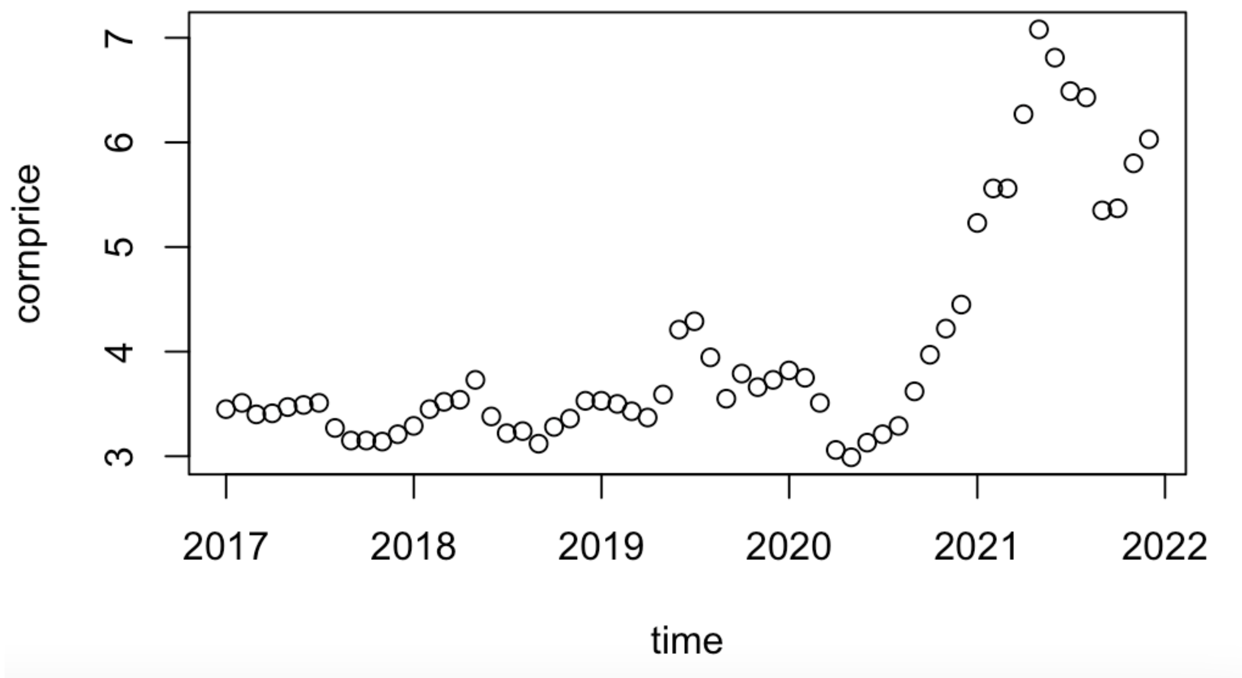
7o. 1) milk price trend



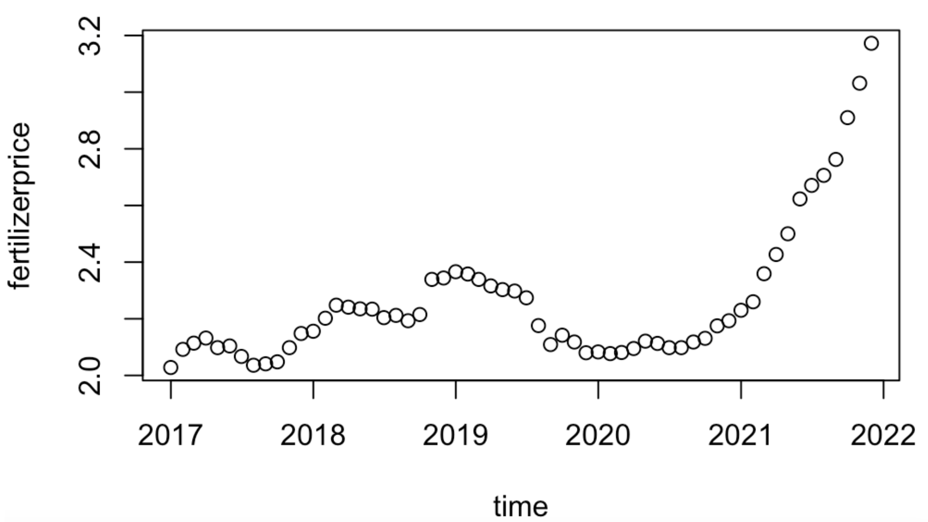
7o. 2) milk quantity trend (could observe the seasonal quantity variation, but overal, quite stable quantity, as the variation of the quantity is depending more from the production side)



7o. 3) corn price trend (could observe that is largely influenced by the “global supply chain crisis” caused by the pandemic)



7o. 4) price of “fertilizer and pesticide” trend (could observe that is largely influenced by the “global supply chain crisis” caused by the pandemic)



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